LEARNING 6 EXPERIENCE

Nucleic Acid to Protein

PROLOGUE DNA stores the information of the cell; proteins are the biomolecules that make the cell. What is the relationship between these two biomolecules?

Stored information is just that: information that is in storage, waiting to be used. Information in the blueprints for a house awaits the construction team that can translate the symbols and diagrams into the substance of a house; the notes in musical scores only come to life when the musician translates the notes into the complexity of musical sounds. How is the information in DNA, specifically in the sequence of its nucleotides, translated into proteins which, in turn, carry out many functions?

In this learning experience, you will be exploring the cellular processes in which the information in DNA is expressed as the protein the cell needs to carry out all of its functions.

The Messenger Tells All

READING

If DNA is found in the nucleus and protein is made in the cytoplasm (as we now know it is), a logistical problem seems to exist. In 1957, shortly after describing the double helical structure of DNA, Francis Crick hypothesized that there needed to exist an intermediate translator of the information between DNA and protein, something that could carry the information from the DNA in the nucleus to the site of protein synthesis in the cytoplasm. The "central dogma", as it came to be known, stated that information stored in DNA was carried by another kind of molecule. In 1960 this "other molecule" was identified as another kind of nucleic acid, *ribonucleic acid* or

RNA (see Figure 6.1). In ensuing years, scientists learned that, in general, only one strand of the DNA double helix was copied into RNA.

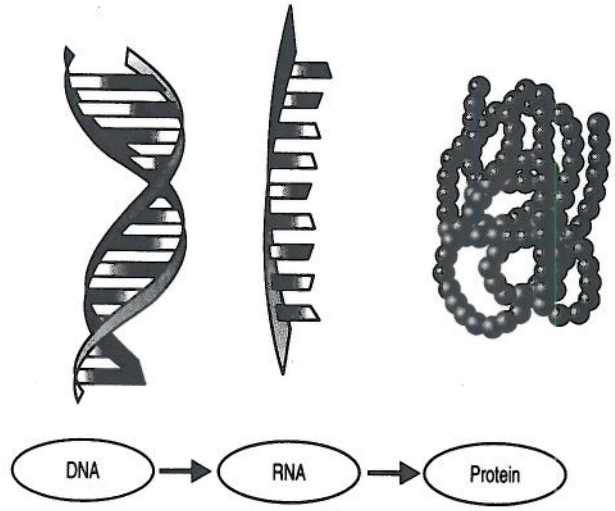

Figure 6.1
The information in DNA is used to assemble proteins.

The role of RNA is essential. Just as monks copied or "transcribed" writings of manuscripts for distribution in medieval times, the information in DNA is transcribed or copied into RNA molecules which look very similar to the original but have several characteristics which distinguish RNA from DNA.

RNA almost always consists of a single strand, not a double helix. Another significant difference between RNA and DNA is the sugar. RNA contains the sugar ribose instead of the deoxyribose sugar found in DNA. The structures in Figure 6.2 indicate the difference in the sugar component of the two types of nucleic acids.

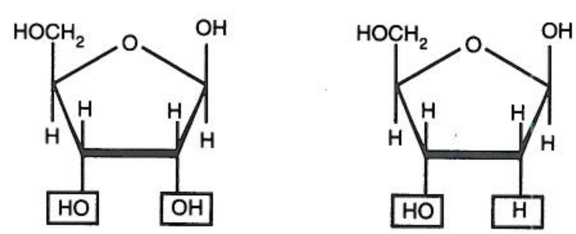

Figure 6.2
RNA is chemically like DNA except for its sugars. Each ribose has an additional oxygen atom compared with deoxyribose. Note the presence and the location of the oxygen in the sugar of the RNA and DNA molecules.

A further difference between RNA and DNA is in the composition of one of their bases: DNA has thymine; instead of thymine RNA has the base *uracil*. The difference in these bases is shown in Figure 6.3.

Transcription is the process by which information encoded in DNA is transferred to an RNA molecule. The information must be copied because DNA does not leave the nucleus. Just as an architect might protect building blueprints from loss or damage by keeping them in a safe or locked place, your cells protect DNA by keeping it safe in

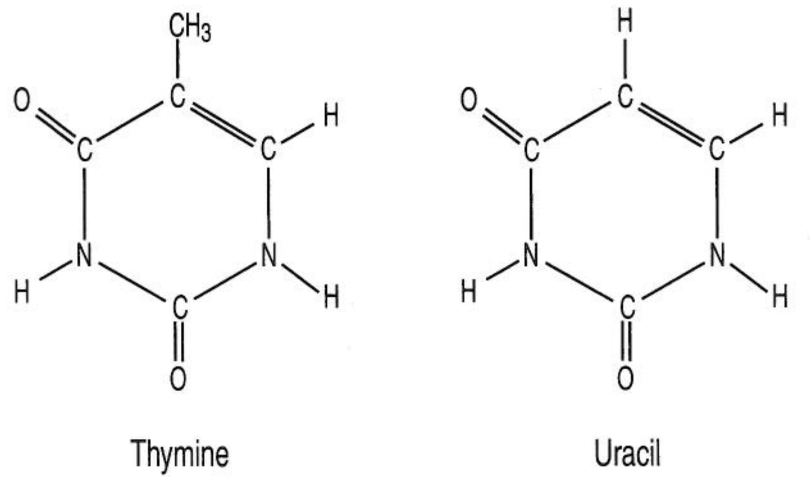

Figure 6.3
The difference between thymine and uracil

the nucleus. Instead, copies of the DNA are made and then sent into the cell's cytoplasm. These copies are the RNA. The RNA then directs the assembly of proteins.

The process of transcription is similar to replication. The DNA chains unwind and separate. The chain begins to build a complement of itself using RNA nucleotides present in the nucleus. Each DNA base is paired with its complementary RNA base. Cytosine is paired with guanine, but because RNA contains uracil instead of thymine, adenine is paired with uracil. In this way, the RNA strand is gradually built. In general, only one of the DNA strands has information to be used for the protein and, therefore, only this strand is copied into RNA. This DNA strand is called the *"sense" strand.* (As you might guess, the other strand is called the *"anti-sense"* strand.)

After transcription of the DNA is complete, the newly transcribed RNA leaves the nucleus. It passes through pores or openings in the nuclear membrane into the cytoplasm, where it then begins to direct the assembly of proteins. This molecule is called *messenger RNA (mRNA).* RNA also plays other roles in the cell, as you will see. Its chemical characteristics and structure enable it to move readily from the nucleus to the cytoplasm. RNA is also more easily broken down (degraded) than DNA. This feature gives the cell a great deal of flexibility and control in what information it expresses as protein. When the cell no longer has need of the information encoded in a particular sequence of DNA, it can stop transcribing it into RNA by various control mechanisms. The RNA already in the cell will eventually be degraded and the cell will no longer make that protein and, therefore, will not express that characteristic.

ANALYSIS

1. Why is it that the information encoded in the DNA is transcribed into RNA and then translated rather than being translated directly?

2. Describe how each of the building blocks for DNA (see Figure 6.4) differs from those for RNA.

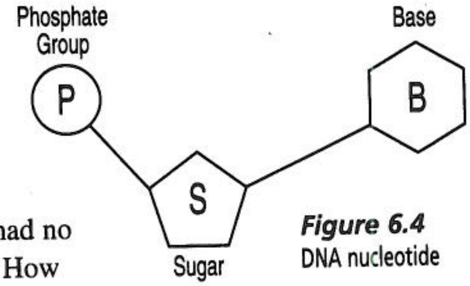

Figure 6.4
DNA nucleotide

3. Envision an organism that had no DNA, that used RNA only. How might such a system carry out the transfer of information? What might be the advantages of such a system? The disadvantages?

4. Use the DNA model you created in Learning Experience 5. Separate the strands of the model by separating the chains along the central hydrogen bonds. Choose one strand of DNA as the sense strand and determine the sequence of its mRNA.

READING

Cracking the Genetic Code

In 1961, Marshall Nirenberg figured out how information was stored in DNA. He "cracked the code" by introducing an mRNA strand consisting solely of uracil nucleotides (as in UUUUUUUUU) into an extract of broken cells which was capable of making proteins in a test tube. From this sequence he obtained a protein made entirely of a single kind of amino acid, phenylalanine. When an mRNA containing the sequence AAAAAAAAA was placed in the tube, a protein consisting of another single amino acid type, lysine, was obtained. All possible RNA sequence combinations were tried. Using this approach, scientists were able to determine that the nucleic acid code in DNA occurred in triplets; that is, a series of three nucleotides in RNA (such as UGA) specifies a particular amino acid. Each nucleotide triplet is called a *codon.*

Using Nirenberg's technique, scientists were able to decipher the code for all 20 amino acids. The result of all this work is the decoder of protein synthesis, the codon table in Table 6.5. With the aid of this table, the amino acids encoded in the RNA can be identified. The sequence of the bases in each codon determines which amino acid will be added next to a growing protein chain. In turn, the sequence of amino acids will determine the shape and, ultimately, the function of that protein.

ANALYSIS

1. Use Table 6.5 to decode the triplet AUG. Try decoding a few more by jotting down any triplet of RNA nucleotides and seeing if you can decode it. Does it seem as if all triplets have a corresponding amino acid? How do you know?

G = guanine
C = cytosine
A = adenine
U = uracil

codons	GCA GCC GCG GCU	AGA AGG CGA CGC CGG CGU	AAC AAU	GAC GAU	UGC UGU	CAA CAG	GAA GAG	
Abbreviations for amino acids	ala	arg	asn	asp	cys	gln	glu	
codons	GGA GGC GGG GGU	CAC CAU	AUA AUC AUU	UUA UUG CUA CUC CUG CUU	AAA AAG	AUG	UUC UUU	CCA CCC CCG CCU
Abbreviations for amino acids	gly	his	ile	leu	lys	met	phe	pro
codons	AGC AGU UCA UCC UCG UCU	ACA ACC ACG ACU	UGG	UAC UAU	GUA GUC GUG GUU		UAA UAG UGA	
Abbreviations for amino acids	ser	thr	trp	tyr	val		stop	

Table 6.5
Each amino acid is coded for by three mRNA bases arranged in a specific sequence called a codon.

For ease of writing, the 20 amino acids can be abbreviated as follows:

ala	alanine	gly	glycine	pro	proline
arg	arginine	his	histidine	ser	serine
asn	asparagine	ile	isoleucine	thr	threonine
asp	aspartic acid	leu	leucine	trp	tryptophan
cys	cysteine	lys	lysine	tyr	tyrosine
gln	glutamine	met	methionine	val	valine
glu	glutamic acid	phe	phenylalanine		

2. All communication needs punctuation. Which codons represent punctuation?
3. Find the amino acids encoded by UCU, UCC, and UCA. What do you observe? What does this mean?

DANCES WITH RIBOSOMES

ACTIVITY

INTRODUCTION If DNA is the master blueprint of the cell, and RNA molecules are the copies to be distributed as the guide to the building process, then the components of the protein synthesis machinery are the construction team. The *ribosome* is the site of protein synthesis and is the structure that holds all the pieces in place. Found in the cytoplasm, the ribosome is comprised of about 50 different kinds of

proteins all wrapped up in a structural RNA. The ribosome has a special place where mRNAs bind.

Transfer RNAs (tRNA) are the actual translators of the code. These are a group of RNAs that have a twisted loop structure made up of nucleotides. At the loop end there are three nucleotides (*anticodons*) which match the sequence of a codon triplet in the mRNA; at the other end is an amino acid, bound to the tRNA. Figure 6.6 shows an example of tRNA. The codon sequence in the mRNA would be UUU. The anticodon on the tRNA is therefore AAA and the amino acid at the other end would be phenylalanine. The sequence at the end of the tRNA loop matches the mRNA sequence (much the way two strands of the DNA sequence match) and brings along with it its amino acid.

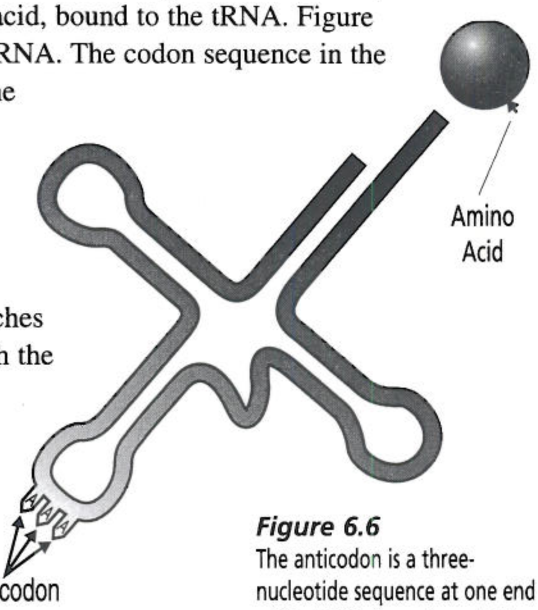

Figure 6.6
The anticodon is a three-nucleotide sequence at one end of the tRNA. An amino acid is attached at the opposite end.

In this activity, you will model protein synthesis. You and your classmates will take on the various roles of the protein synthesis machinery. The classroom represents the cytoplasm, and the corridor outside the classroom represents the nucleus.

ROLES

- mRNA:
  2–3 students become the single strand of mRNA
- ribosome: 1 student is the ribosome
- enzymes which assemble amino acids into a protein chain: 2 students with tape and string
- transfer RNA (4 different types, multiple copies of each—GAC, CUU, AAA, and UUC—each of which holds an inflated balloon (amino acid) to which it is color coded): remaining students in the class.

The Procedure describes, in detail, the process of protein synthesis. Once you have assumed your role, you and your classmates will create a

protein as a class. It is important that you understand each step in the process. This "central dogma" of biology is essential to all living things. The information stored in DNA flows through RNA to protein and these proteins are essential for carrying out the functions and determining the characteristics of an organism. In the case of the bacteria *Diplococcus pneumoniae*, the DNA transferred from the virulent bacteria caused the nonvirulent bacteria to make a protein which made it pathogenic to the host.

PROCEDURE

1. The mRNA starts in the corridor (nucleus) and enters the cytoplasm (classroom).
2. The mRNA attaches to the ribosome which has been structured to reveal three nucleotide symbols (a codon) at a time. As mRNA moves through the ribosome, the person holding the ribosome calls out the revealed codon.
3. The appropriate tRNA with the complementary anticodon comes up to the ribosome bringing its attached amino acid (balloon).
4. The enzymes take the balloon from the tRNA and tape it to the string that they are holding.
5. The mRNA continues to move through the ribosome exposing each codon.
6. Appropriate tRNAs bring balloons (amino acids) that continue to be added to the protein chain. When tRNA gives up its amino acid balloon, it goes to pick up the appropriate free amino acids until it will again be needed. Free amino acids (uninflated balloons) will be stored in a designated area in the room (cytoplasm) where they may be retrieved by a tRNA that has released its amino acid (balloon) to the growing protein chain on the ribosome.
7. When the complete chain of amino acids has been assembled, the enzymes will detach the chain from the ribosome and suspend it where it will be visible to the entire class.

ANALYSIS

1. Create a concept map that summarizes protein synthesis—the process by which information is transferred from DNA to protein in the cell. Use the following terms in your map: nucleus, cytoplasm, ribosome, transcription, translation, DNA, mRNA, tRNA, amino acid, protein,

enzyme. Be sure to include other terms from this module.

2. Suppose the mRNA "message" that leaves the nucleus and attaches to the ribosome were changed so that the final codon was GUA instead of the existing GAA. What would be the composition of the resulting protein chain?
3. What would be the nucleotide composition of the DNA sense strand that produced the change in mRNA?
4. What would be the nucleotide composition of the DNA sense strand that produced the original mRNA?
5. Using your answers to questions 2, 3, and 4, determine how the original double-stranded DNA molecule could have changed to produce the new messenger RNA. Such a change in DNA is called a *mutation.* You are being asked to figure out specifically what mutation in DNA might have occurred to produce the changes in RNA and the protein chain that is ultimately produced.

EXTENDING IDEAS

ON THE JOB

GENETICIST Are you interested in how traits are passed from one generation to another? Geneticists are scientists who study how biological traits originate and how they are passed from one generation to the next in various life forms. Geneticists usually specialize by studying one particular type of organism such as plants, animals or other organisms. Plant geneticists plant seeds and then grow the plants to maturity in order to look at both chromosome structure and chromosome number of a cell, to use equipment to identify the gene sequence of a particular piece of DNA, or to look for variations from one species to another. Once the location of genes has been identified on the chromosomes, geneticists might insert the gene into a cell and in tissue culture replicate the gene sequence so there are many copies of it. Molecular biologists or genetic engineers are able to manipulate the gene sequence. Geneticists studying animal organisms also watch the animals grow to maturity and then look at both chromosome structure and number of a cell to either identify the locations of specific genes or to look for variations from one species to another. The laboratory techniques and procedures used by molecular biologists are not unique to molecular biology, but are the techniques and tools used by chemists and cell biologists. For someone with a high school degree or a two year college degree,

positions as a laboratory technician are available. A four year college degree makes it possible to be a laboratory assistant or research geneticist. With a master's or doctoral degree, geneticists can teach in a university or pursue independent research in a university or laboratory. Classes such as biology, chemistry, math, English, and computer science are necessary.

TEACHER Do you like sharing what you know about microorganisms or how disease is caused? Teachers combine their knowledge of a subject with the ability to make it interesting and communicate clearly. Teachers at all grade levels would plan what topics to cover and what activities or labs to use to illustrate the topic, prepare activities or labs (this includes collecting all the materials and setting up the activity), work with students as they do the activities, write and grade quizzes and tests. A teacher who works in an elementary school might teach one class all subjects, including science, or could just teach science and work with all the classes in the school. Elementary school science consists of lots of activities and encouraging students to ask a lot of questions and wonder about the world. A middle school science teacher teaches general science courses which focus on science as a way of thinking and continues to build on the concepts students explored in elementary school. High school science teachers most often teach in one particular subject area (biology, chemistry or physics), although many are versatile and can teach in several subject areas. High school science explores science concepts in depth and also looks at the science within social, historical, ethical, and political contexts. Not all science teachers work in a school. Some work in museums, zoos, aquariums or science centers, teaching the general public and taking classes on school field trips. A minimum of a four year college degree is required with classes in your subject area and the completion of a teacher preparation program. The teacher preparation program includes courses on child development and on teaching methods as well as student teaching. Requirements for teacher certification vary from state to state. Some teachers have a master's degree in education or science education. Classes in subjects such as biology, chemistry, physics, mathematics, English, and psychology are recommended.